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LIGHT-LINE VISUAL LANDING HEAD-UP DISPLAY EVALUATION, PHASE I

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The Light-Line Head-Up Display (HUD) Evaluation is part of an exploratory program being conducted by the Air Force Flight Dynamics Laboratory, Flight Control Division (AFFDL/FGR), Wright-Patterson AFB OH, to investigate HUD systems/concepts to aid the pilot in maintaining a specified vertical path during visual landings. The HUD was evaluated at Randolph AFB by the USAF Instrument Flight Center, Research and Development Division (USAFIFC/RD), to determine the pilots' acceptance and operational utility of the Light-Line → OVER

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HUD from a pilot factors point of view.

The Light-Line HUD shows flightpath angle, angle-of-attack derived speed error, and lateral touchdown zone information in an easily interpretable form. The HUD (designed as a visual landing aid) provides the pilot a three-dimensional cue (light-line wand). The wand appears to be suspended in space emanating from the pilot's chest, and terminating on the desired aim point. The light-line display system which is focused at infinity, depicts a combination velocity vector (four strobing-line segments) and flightpath vector (transverse bar). Thus, the pilot is provided augmentive information without having to focus on the display. The wand has the capability to move laterally across the focal plane as well as longitudinally. This provides a realistic representation of the flightpath vector in three-dimensional space.

The pilot is provided two different modes of operation. In one mode (director mode), the light-line wand, when positioned and maintained on the desired aim point, will automatically direct the pilot to fly a preselected flightpath angle. In the second mode (displacement mode), the light-line displays position and trend information in two separate cues (flightpath scale and velocity vector). The flightpath scale depicts the angle to a selected aim point/target; while the wand indicates the flightpath vector of the aircraft at that particular instant.

Analysis of the data indicates the Light-Line HUD as presently designed was not considered satisfactory for inclusion in USAF aircraft. However, as a result of the evaluation, several advantageous features were enumerated by subject pilots and project pilots. These features appear to warrant further development of the light-line concept for use as a landing aid and also in other areas of the flight regime.

The automatic mode (director mode) was considered the most useful in that it reduced pilot workload and increased the overall precision of the straight-in approach. The displacement mode was not as useful to the pilots because of increased workload due to mental calculations required to effectively use this mode.

The utility of the Light-Line HUD was degraded during crosswind conditions, turbulence, and when flying in a crab. The main problem was due to the extreme sensitivity of the light-line wand which made it difficult for the pilot to maintain the desired aim point. The concept of displaying angle-of-attack (AOA) derived speed error in a form of strobing segments appeared to have some merit; however, pilots had difficulty in interpreting the information. Although the Light-Line HUD has several design deficiencies which produced negative responses, the HUD was useful under certain conditions and warrants further investigation.

PREFACE

This technical report documents the results of a study conducted under USAF contract number AF33(615) 72-C-1867, describing the use of a head-up display to assist approach and landing in the T-38 aircraft under visual flight conditions. The report was prepared by the USAF Instrument Flight Center, Research and Development Division.

Contract AF33(615) 72-C-1867 was initiated under USAF Project 6190, "Control-Display for Air Force Aircraft and Aerospace Vehicles," which is managed by the Flight Deck Development Branch (AFFDL/FGR), Flight Control Division, Wright-Patterson Air Force Base, Ohio. The work was performed as a part of Task Number 6190-02-09 under the guidance of Mr. William Augustine (AFFDL/FGR) as task engineer. Flying activities were conducted by the Research and Development Division, USAF Instrument Flight Center, Randolph AFB, Texas. Major Manuel Tapia was project officer and pilot experimenter for this study. Human Factors support was provided by Mr. Gabriel Intano, USAFIFC/RDU.

This technical report has been reviewed and is approved.

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INTRODUCTION

BACKGROUND

The Light-Line Head-Up Display (HUD) Evaluation is part of an exploratory program being conducted by Air Force Flight Dynamics Laboratory, Flight Control Division (AFFDL/FGR), Wright-Patterson AFB, to investigate HUD systems and concepts to augment pilot judgment and perception during visual landings. This exploratory program was initiated in response to Air Training Command's request that the AFFDL investigate ways of providing displays to aid the pilot in maintaining a specified vertical path during landing approaches. After careful analysis of T-38 aircraft landing accidents, AFFDL defined two coordinated areas of research. The first was to define the normal visual flightpath flown in IFC/RD T-38 aircraft. This investigation (CDG-VLP-1, VFR Approach Profiles in T-38 Aircraft) was conducted to obtain baseline data for comparing aiding systems. The second effort has been directed towards developing a HUD system that will provide the pilot a visual display to decrease his workload and augment his judgment.

The first attempt at providing the pilot with a system to assist him in controlling an aircraft's vertical path to the runway was the Mechanical External Path Angle Director Display (MEPADD). The MEPADD was an electromechanical device mounted on the nose of the T-38 aircraft. It was designed to provide the pilot flightpath computations and display to direct the aircraft along a preselected flightpath angle to the runway. However, mechanical problems interfered with the operation of the system; therefore, AFFDL elected to use a more conventional HUD incorporating a combiner glass. Hence, the HUD system (developed by AFFDL and built by Sundstrand Data Control, Redmond, Washington) was installed in the Instrument Flight Center, Research and Development Division (IFC/RD) T-38 to replace the MEPADD.

The HUD system, designated Visual Landing Aid (VLA), was evaluated by the USAFIFC/RD at Randolph AFB TX. The evaluation of the VLA was conducted in two phases, T-38 Visual Landing Aid Study, Phase I (IFC TR-73-7) and T-38 Visual Landing Aid Study, Phase II (IFC LR-73-5). The results of these evaluations provided the basis and recommendations for improving visual landing aids. AFFDL then developed a HUD, designated Visual Approach Monitor (VAM), designed to aid pilots flying large-bodied aircraft. The VAM was evaluated in a C-5 Galaxy at Altus AFB OK, by Detachment 1, HQ MAC, and the 443 MAW.

Even though the results of these evaluations indicated that the HUDs, VLA, and VAM aided the T-38 and C-5 pilots during visual meteorological conditions (VMC) straight-in approaches, pilots indicated that there were some deficiencies in the system. Therefore, based on the results and recommendations of these reports AFFDL/FGR developed the Light-Line HUD (figure 1). Since IFC/RD conducted the pilot factors (PIFAX) evaluation of the VLA and assisted with the VAM evaluation, AFFDL requested that IFC/RD conduct the PIFAX flight evaluation of the Light-Line HUD system.

The Light-Line HUD is designed to display flightpath angle, angle-of-attack derived speed error, and lateral touchdown zone information in an easily interpretable form. This HUD provides the pilot a three-dimensional wand (light-line) which appears to be suspended in space emanating from the pilot's chest, and terminating on the selected/desired aim point. The light-line is a combination velocity vector (four strobing-line segments) and flightpath vector (transverse bar) focused at infinity. Thus, the pilot is provided augmentive information without having to focus on the display (figure 3). The light-line wand has the capability to move laterally (as well as longitudinally) across the focal plane and provides realistic representation of the flightpath vector in three-dimensional space. The pilot is provided two different modes of operation. In one mode (director mode), the light-line wand (when maintained on the desired aim point) will direct the pilot to fly the flightpath angle that he selected on the controller module regardless of the initial aircraft approach angle. In the second mode (displacement mode), the light-line displays position and trend information in two separate cues (flightpath scale and velocity vector). The flightpath scale depicts the angle to a selected aim point or target while the wand indicates the flightpath vector of the aircraft at that particular instant.

TEST OBJECTIVES

General

To conduct a pilot factors flight evaluation of the Light-Line HUD's conceptual application and potential uses as a visual aid to the pilot during different phases of flight.

Specific

1. To determine by flight evaluation, pilot acceptance and operational utility of the light-line's format of displaying:

   a. Aircraft velocity vector.

   b. Flightpath angle.

   c. Speed information in the form of a strobing symbol.

   d. Heading error.

   e. Flightpath intercept point.

2. To determine both pilot preference for, and potential pilot operational problems associated with the two modes (director and displacement) of light-line operation.

METHODOLOGY

The Light-Line HUD was installed in IFC/RD T-38 aircraft, SN 60-0582, by Sundstrand Data Control at Snohomish Co., Paine Field, Washington. Except for the initial acceptance flights, the evaluation was conducted in the Randolph local flying area. The majority of the visual straight-in and overhead approaches were flown at Seguin Auxiliary Field, while the instrument approaches were flown at Randolph AFB and Kelly AFB.

The original test plan called for a minimum of ten (10) subject pilots, each flying similar flight profiles to evaluate the system's conceptual application and its merits as a landing aid.

To obtain an adequate subjective evaluation of the conceptual uses of this type display, twelve (12) highly experienced IFC Instructor Pilots were selected to fly the profiles. (Only two of these individuals had flown a HUD previously.) Each pilot flew various maneuvers which simulated air-to-air and air-to-ground target acquisition/tracking. Additionally, pilots were asked to conceptually evaluate the potential uses of this type system (as configured or modified) relating to maneuvers such as air refueling, formation, join-ups, and terrain avoidance. Subject pilots were also asked to evaluate the HUD during normal flight maneuvers such as climbs and descents, level flight, etc. For the air-to-ground acquisition and tracking, the following parameters were used due to local area airspace and flying directives restrictions.

Altitude 10 - 20M

Airspeed 220 - 300 k

Pilots were briefed on the operation and mechanical limitations of the HUD, and were asked to assume that the system could be mechanized to allow them to fly extreme FPAs to the desired target, that is, assume the system was capable of providing 30 - 45° of FPA automatically in the director mode (see description of test item). Pilots were also asked to use the different combinations available with the HUD (for example, director, displacement, director mode with heading inhibit, etc.). One phase of the evaluation was designed to have the subject pilot evaluate the conceptual application of the Light-Line HUD. After the high altitude portion of the profile, the pilots were given the opportunity to fly the system in the landing pattern.

Subjects flew visual overhead patterns and straight-in approaches to evaluate the two modes of operation. IMC transition to VMC approaches were flown when such weather conditions became available. The twelve subjects flew a total of 46 sorties (approximately eighty-six approaches each) using the director and displacement modes for straight-in approaches. Approximately 30 approaches were flown by five pilots during instrument flight conditions (IMC transition to VMC approach) utilizing both modes of operation. Approximately 140 approaches were flown in the visual overhead pattern (approximately 70 each, director and displacement modes).

PREFLIGHT BRIEFING

Each subject pilot was thoroughly briefed and instructed in the light-line operation and mission profile. The pilots were instructed to subjectively evaluate the direction of light-line strobing and the heading error feature during their first flight. Thereafter, they were to use the strobe direction they preferred.

DATA COLLECTION

Project pilots recorded the subject pilots' comments and significant problems encountered by the subject pilots while flying the Light-Line HUD. The test plan called for each subject pilot and project pilot to complete an in-flight rating card after a series of maneuvers in the landing pattern. However, due to the short period between approaches and traffic congestion requiring the pilots to be vigilent for other aircraft, this requirement was deleted.

After each flight, subject pilots were debriefed by the project pilot. A postflight questionnaire (atch 1) was given to the subject pilots after the third sortie. The subjects completed items accomplished through the end of the third sortie and returned the completed questionnaire after the last sortie.

DESCRIPTION OF TEST ITEM

The Light-Line system consists of three major components: (1) the Light-Line Head-Up Display assembly (figure 1), (2) a flightpath computer (figure 1), and (3) the controller module (figure 2).

1. Light-Line HUD Assembly. The HUD assembly is designed to be mounted on a modified glare shield of the T-38 aircraft. It consists of a symbology generator and curved combiner lens. The display provides an instantaneous field of view, measured from the pilot's Eye Reference Position (ERP) of 9.5° vertically and 21.5° laterally (assuming a 20-inch ERP to lens distance). The pilot is provided augmentative information which is collimated by the combiner lens and reflected into his optical field of view. The display provides the pilot four distinct visual cues (an artifical horizon line, a vertical protractor scale, a bar symbol or command bar, and a light-line) which appear amber on the combiner.

The artificial horizon line extends horizontally across the display and is stabilized in both pitch and roll. The center of the horizon line is a diamond symbol (that is the extended center line of the aircraft) and represents the aircraft heading against the "real world" background.

The vertical protractor scale (flightpath angle scale) is located on the left side of the lens, and when viewed against the real world, provides approach slope indication to the runway. The numbers above zero are in

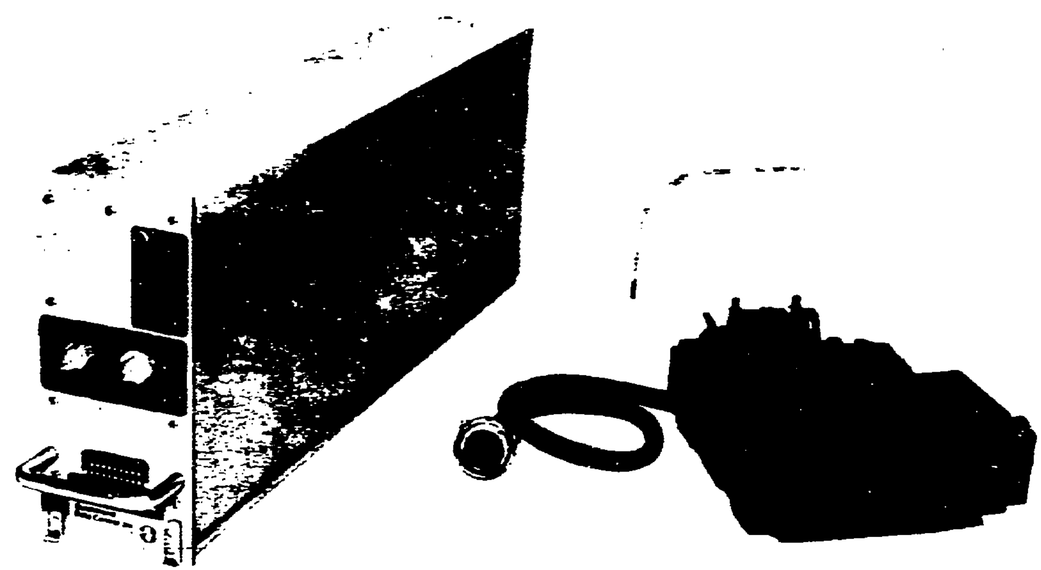


Figure 1. Computer and Head-Up Display Assembly.

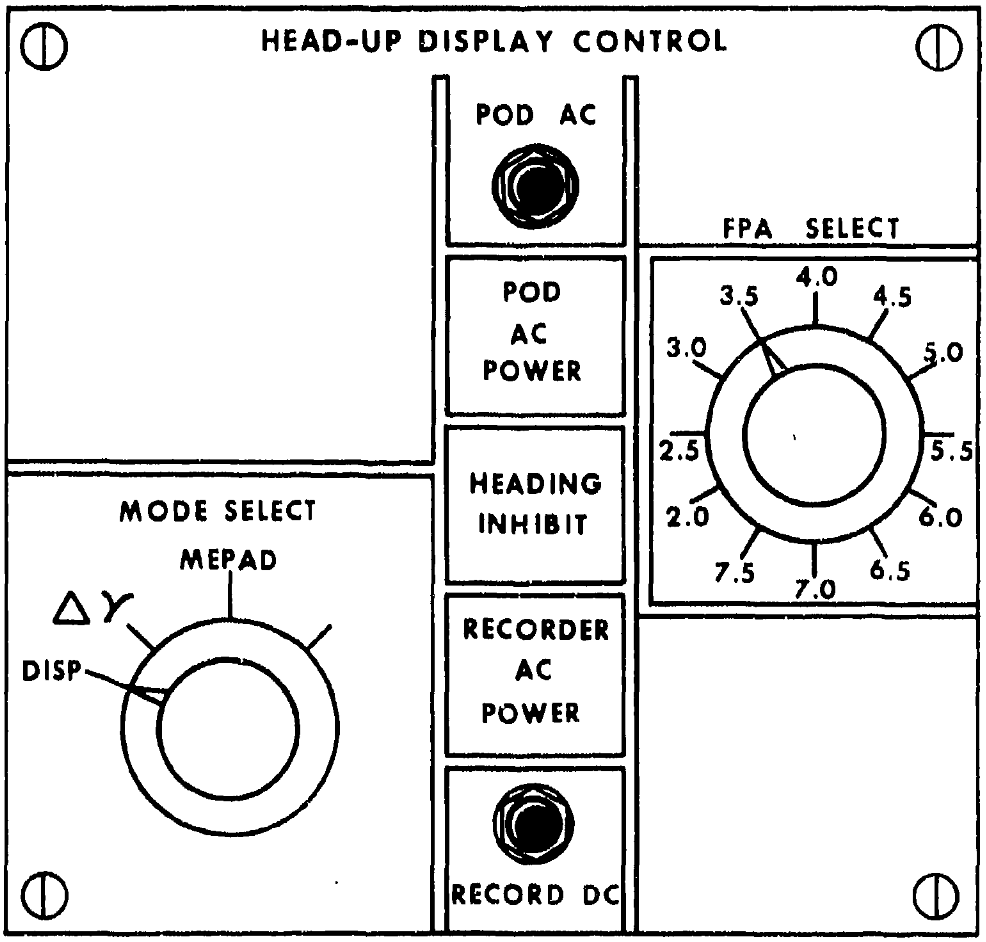
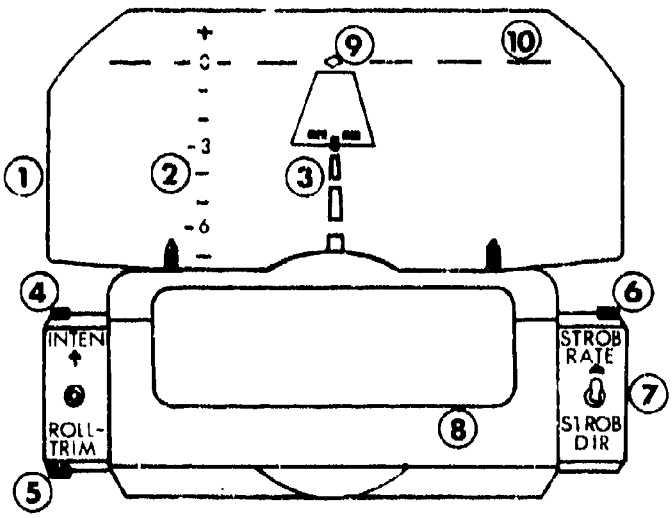


Figure 2. Head-Up Display Control.



1. COMBINER LENS

Fabricated of optically ground and coated acrylic plastic. It collimates the display to near infinity.

2. APPROACH ANGLE SCALE

Displayed vertically - on left side of the lens. Numbers on the scale above zero are in plus (+) degrees to the horizon; those below are in minus (-) degrees. Slope angle to the runway aiming point is read off directly.

3. LIGHT-LINE

An integrated cue that is a combination of the velocity vector - 4 strobing line segments, and flightpath vector - transverse bar.

4. INTENSITY CONTROL

Adjusts the intensity of the image from low to full bright depending on background light level. Once set, an automatic contrast feature maintains readability throughout a wide range of ambient lighting.

5. ROLL TRIM

Allows adjustment of horizon line to overlay the outside world. Eliminates the effect of vertical gyro roll erection errors.

6. STROBE RATE

Adjusts the rate at which the velocity vector bar segments strobe as a function of airspeed/angle-of-attack error signal.

7. STROBE DIRECTION

A switch that allows changing the strobe direction as a function of airspeed/angle-of-attack error.

8. DISPLAY BUMPER

The bumper acts as a crash pad to prevent injury in the event of striking the display.

9. AIRCRAFT HEADING

An elongated diamond symbol that is the extended center line of the aircraft. The symbol viewed against the "real world" background is the aircraft heading.

10. EXTENDED HORIZON

An artificial horizon line that is stabilized in pitch and roll. The extended horizon is the aircraft's extended horizon line. It is usually above the visible earth horizon because of earth curvature at altitude.

Figure 3. Basic Display Format.

plus (+) degrees to the horizon; those below are in minus (-) degrees. Slope angle to runway aim point is read directly off the vertical protractor scale.

The bar symbol is the termination of the instantaneous flightpath vector, or instantaneous touchdown zone (aim point) in one mode (displacement mode); or a command bar (director mode) that can be held on the desired touchdown point and cause the aircraft to terminate the approach at a predetermined flightpath angle. The alignment of the bar symbol with the protractor scale is the flightpath angle of the aircraft in the displacement mode.

The light-line is displayed on the combiner lens as a three-dimensional segmented wand. The wand appears to emanate from the pilot's chest and terminate on the transverse bar which is the termination of the light-line. The four segments plus the transverse bar combine to provide a three-dimensional wand which appears as a segmented T (figure 3). The light-line image is formed on a servo-positioned rod located in the display body focal plane and is projected on the combiner lens. The wand is positioned by two DC torque motors to translate the collimated end of the light-line wand along the focal plane in the pitch and lateral axis. The transverse bar is continuously illuminated while the four in-line segments of the light-line illuminate individually and strobe to provide speed error information. The four in-line segments indicate a deviation from the programmed approach speed. If the approach is fast (lower than desired AOA), the four segments will strobe away from the pilot. If the approach is slow (higher than desired AOA), th[illegible]ur segments will strobe toward the pilot. Strobe direction can be reversed [illegible]le switch on the HUD. This will cause reversal of the strobing for a [illegible]ondition. The strobe rate is a function of the speed error (angle-[illegible]ack) deviation; the greater the speed deviation from the desired approach speed (angle-of-attack), the higher the strobe rate. Maximum strobing occurs at approximately 8 to 10 knots from the programmed airspeed. When the aircraft is flown at the proper airspeed and AOA, the four light-line segments will remain motionless providing a segmented T.

The lateral position of the light-line on the combiner lens is directly related to the heading selected on the HSI. As the aircraft heading deviates from the selected runway heading, the light-line will move left or right to a maximum of 9.5° in the lateral axis. The heading error signal positions the light-line such that the light-line will remain at the outer limits of the display until the aircraft heading comes within the 9.5° of the heading selected. When the aircraft heading is within the 9.5° the pilot can use it as a director; that is, the pilot will fly towards the wand until the desired aim point is reached. When the light-line is at the outer limits, the pilot can still use the speed error function to maintain proper airspeed. The heading feature is controlled by a switch on the controller module labeled "heading inhibit." When the switch is in the normal mode (light out), the wand is providing heading information; however, if the switch is in the inhibit position (light-on), the light-line will be stowed to the center position. Although the light-line is not providing heading information, it still provides speed error (angle-of-attack) information.

The display background (that is, the flightpath scale and horizon) is generated in the aft portion of the display symbol generator (projection booth) and transmitted to the focal plane of the combiner lens by a fiber optics magnifier lens. The artificial horizon image mechanism is suspended in bearings which allow it to rotate about the normal axis of the fiber optics; thus it is stabilized in pitch and roll.

Additional display features are as follows: The image lighting brightness is continuously variable and controlled by a thumb wheel attached to a potentiometer located on the back of the display beside the bumper handle (figure 3). The potentiometer output is fed back into the lamp voltage control circuit such that the brightness of the display corresponds to the level determined by a reference voltage from the potentiometer. A photocell measures the intensity of the ambient light and controls the contrast about the pilot-set intensity level.

NOTE: Loss of a validity signal supplied by the computer failure monitor circuit will extinguish all display lights. This scheme has gained the greatest acceptance because incorrect information disappears and there is no ambiguity as to failure.

Automatic image leveling is provided to compensate for installation wear, flexing and lens position via an inertial grade longitudinal accelerometer mounted on the combiner lens axle. This feature eliminates optical boresighting of the display to maintain precise visual alignment to the "outside world" after each flight.

For maintenance purposes, a small "align test" button can be depressed with a pencil or similar object. This feature is provided to compare the light-line display alignment with the aircraft vertical gyro. If the difference between the display alignment and the aircraft vertical gyro exceeds 4.5°, the light-line system will shut down.

The Light-Line HUD is designed so that the pilot has easy access to the display controls which are located at the rear of the unit; that is, in front of the pilot. The controls consist of:

a. A thumb wheel to adjust the display brightness.

b. A strobe rate control to adjust the rate of strobing of the light-line symbol as a function of the angle-of-attack error (deviation from the desired airspeed/AOA).

c. A strobe direction switch, to allow the pilot to reverse the direction of strobing.

NOTE: This switch will only be installed on the test item to determine the direction of strobing that provides the best information.

d. A roll trim control knob to compensate for roll erection error of the vertical gyro.

e. A small push-button alignment test (for maintenance purposes) is also provided. The pilot can also use this button to "fast erect" the HUD display symbology to mechanically align the system to the aircraft gyro system.

2. The Light-Line Controller Module. The control module is located in the pilot's right-hand console forward of the map case. The controls on the console are flightpath selector, mode selector (gamma or delta gamma), heading inhibit switch, pod aircraft power switch, and recorder power switch.

a. A flightpath angle selector is provided to allow selection of the reference or desired approach flightpath angle in the command (director); that is, delta gamma mode. The range of flightpath selection is from 2° to 7.5° in 0.5° increments. This feature allows the pilot to set the reference light-line flightpath angle to any ILS glide slope angle, permitting monitoring of the approach.

b. The displacement (gamma) and director (delta gamma) mode switch is also located on the controller module providing easy access to mode selection.

c. A heading inhibit switch is located on the control module to allow the pilot the capability to disable the heading function, and thus prevent the wand from moving back and forth across the combiner lens during high performance maneuvers. In the inhibit position (light on), the wand will remain in the center position. However, it will still provide speed error (angle-of-attack) information.

d. The pod instrument and recorder power switch are provided to apply power to the specially instrumented pod which houses the light-line computer and other system components.

3. Flightpath Computer. The light-line computer utilizes pitch and roll information from the aircraft vertical gyro, pitot and static pressure to compute the velocity vector, angle-of-attack error signal from the angle-of-attack computer, and a heading error signal from the heading marker on the HSI. This information is processed and used to position the wand such that it appears as a three-dimensional symbol which represents the flightpath vector of the aircraft. The computer (a 3/8 ATR long standard ARINC box) is located in an instrument pod attached to the IFC/RD T38A aircraft.

OPERATIONAL CHECKOUT (Taken in part from Sundstrand's Pilots Hand Book.)

Prior to flying the aircraft, the light-line should be checked out as follows:

1. Press pod aircraft switch on control module to ON (light should be on).

NOTE: If, after 4 to 5 seconds, you do not see the lighted display on the combiner lens, adjust the intensity control all the way up (figure 3). If still no display is visible, check the light-line circuit breaker on the controller module.

2. Adjust the seat vertically to place yourself in a position where you are sighting over the top of the indicator assembly.

NOTE: When properly aligned, you will barely see the top of the two studs that attach the combiner lens to the indicator assembly. To provide additional flexibility in vertical alignment, the indicator mounting is adjustable in the vertical plane. The seat is adjusted for a comfortable view of the instrument panel and outside world. Adjust the HUD vertically by loosening the clamp screws on each side of the light-line mounting brackets and push the mount up or down until the display is in the proper position (as stated above) and retighten the clamp screws.

3. Ensure that the zero on the approach angle scale is approximately on the visible horizon and that the horizon line is aligned in roll. Adjust the roll adjust knob as required (figure 3).

4. Set the flightpath selector to 6.0°, verify that the transverse bar of the light-line appears at approximately the 4° mark on the flightpath scale in the director mode. Then switch to displacement mode.

NOTE: In the displacement mode, the transverse bar of the light-line should move toward the horizon line and stop at approximately 2°.

5. Verify that the speed or angle-of-attack error line segments are strobing; place the strobe direction switch in the opposite direction and observe that the strobe direction reverses. (Have the AOA probe rotated if not strobing.)

6. With the heading selector on the HSI, set to the aircraft heading. Depress the heading inhibit switch, located on the right-hand console to OFF; that is, no light visible. Slew the heading marker ±15° about the aircraft heading and observe that the light-line slews in a lateral axis (in the same direction as the heading marker).

7. Verify that all controls and switches on the light-line indicator and controller console are in the desired position.

ACQUISITION OF FLIGHTPATH

The purpose of the displayed light-line cue is to present the pilot with information which assists him in acquiring, tracking, and monitoring a desired glide slope to touchdown with minimum distraction from other tasks. The pilot is provided an option of selecting 2 modes of operation, director or displacement.

Director Mode

The purpose of this display mode is to present both position and trend information as a single cue (figures 4 and 5).

The system is programmed so that in level flight the transverse bar is at 2° when a 3° FPA is selected on the controller module. Maintaining the flightpath bar on 2° keeps the aircraft at a constant altitude; that is, level flight. The zero reference on the approach angle scales is slightly above the true horizon by an amount directly porportional to the height of the aircraft above the real world horizon. The horizontal line is the extended aircraft horizon. The earth horizon is below the extended artificial horizon because of the earth's curvature. The velocity vector strobes toward the runway (polarity in normal position). Adjust the strobe rate control to a comfortable setting.

NOTE: The pilot looks through the display at the runway, not at the display itself. In the director mode (delta gamma) holding the flightpath bar on the desired aim point will automatically bring the aircraft to the selected flightpath angle, regardless of initial aircraft approach angle. Display illumination should be kept at the lowest usable level. If the display is too bright, the pilot may experience a tendency to lock his vision onto the display. This must be avoided. Flying the bar should not distract the pilot's attention from observing other visual cues, or from normal cockpit tasks during approach.

Displacement Mode

The purpose of this display mode is to present position and trend information in two separate cues. The position information is provided by reference to the displayed vertical scale. The scale answers the question "Where am I?"; the transverse bar at the end of the light-line is the instantaneous flightpath of the aircraft at that particular instant in time. The transverse bar cue informs the pilot where he is going. The combination of the two cues provides position and trend information (figure 6).

In the displacement mode, the pilot has three tasks. First, he must align the scale with the desired touchdown zone (TDZ); second, he must align the instantaneous flightpath bar on the desired TDZ; and third, he must hold the bar long or short of the TDZ when the approach slope is not at the desired value until the desired slope is reached. For example, if the aircraft is flying a 4° flightpath, and you want to fly a 3° flightpath, then the correction is to fly at a steeper flight angle for a brief period until the 3° flightpath approaches the aim point. Then adjust pitch and power to position the bar on the aim point.

A recommended method has been developed to fly the combination effectively:

a. Align the desired approach slope scale angle with the aim point by adjusting the aircraft thrust/power until the desired scale angle remains relatively fixed on the TDZ.

b. Adjust pitch attitude of the aircraft to bring the bar onto the aim point.

c. Use the bar for trend information, making small corrections with pitch. If the desired scale angle appears to shift off the TDZ, apply or reduce power. Note the angular difference of the scale reading to the desired reading. Place the bar at an angle that will cause an intercept of the desired angle; when the desired angle is near the aim point, bring the transverse bar onto the desired aim point.

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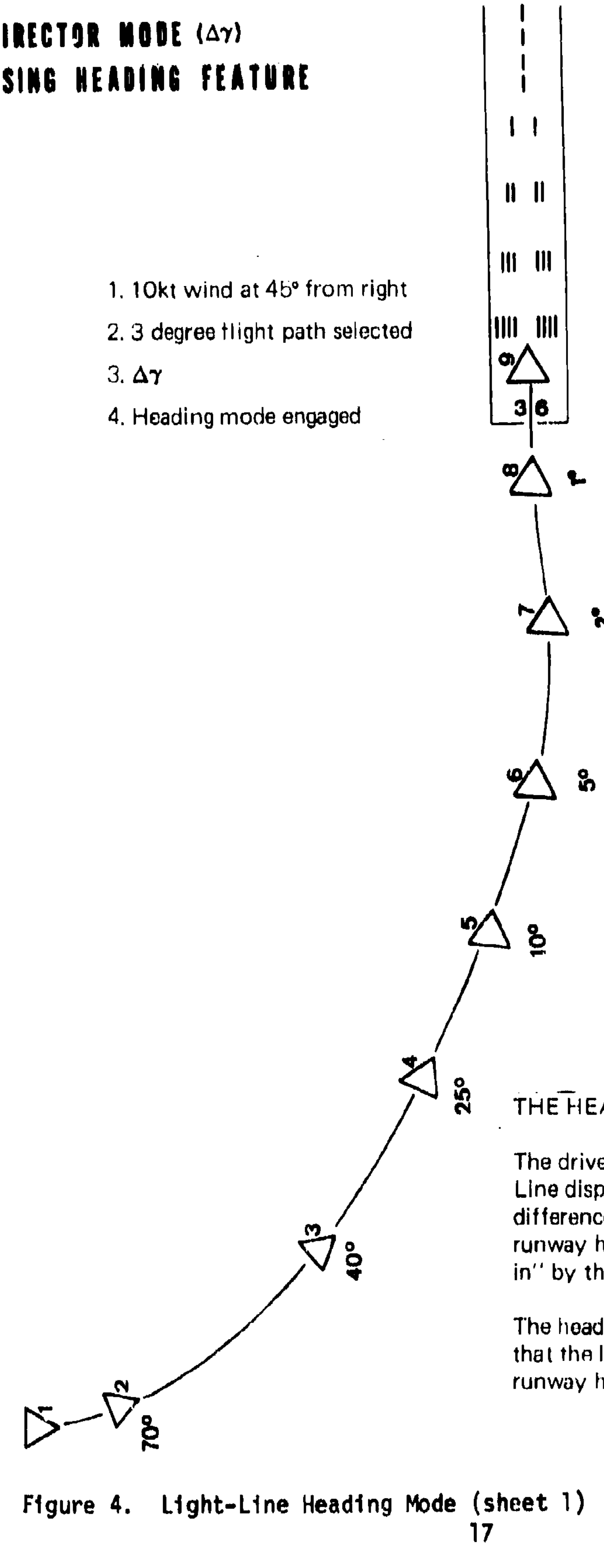
DIRECTOR MODE (Δγ)
USING HEADING FEATURE

1. 10kt wind at 45° from right
2. 3 degree flight path selected
3. Δγ
4. Heading mode engaged



THE HEADING FEATURE

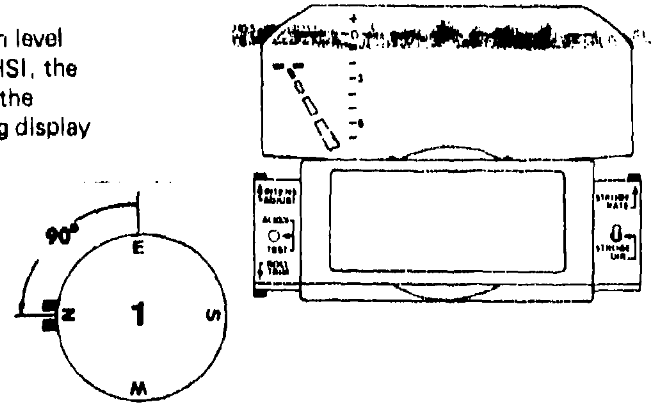
The drive signal for the horizontal axis of the Light-Line display is heading error, consisting of the difference between the actual aircraft heading and the runway heading. The runway heading has to be "bugged in" by the pilot before approach on his HSI.

The heading error signal positions the light-line such that the line always points in a direction parallel to the runway heading independent of aircraft crab angle.

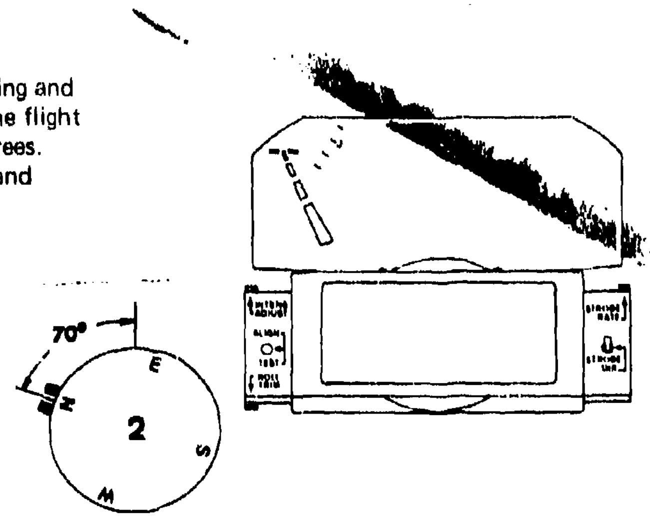
Figure 4. Light-Line Heading Mode (sheet 1)

The Light-Line Heading Mode + Δγ

1.
The approach is started at 1000 ft. altitude from level flight. Runway heading 36 is bugged in on the HSI, the aircraft heading is greater than 90 degrees from the runway heading, therefore the light-line heading display is in the left limit of indicator heading display.



2.
The aircraft starts its turn onto the desired heading and banks 30°. A -3 degree approach is selected on the flight path controller. The flight path is about 2.5 degrees. The pilot looks up, sees the field off to his left, and continues his instrument scan



3.
The aircraft starts to roll out onto the desired heading. The bank angle is 15°. The pilot looks up, notices the field off to his left, looks down to continue his instrument scan.

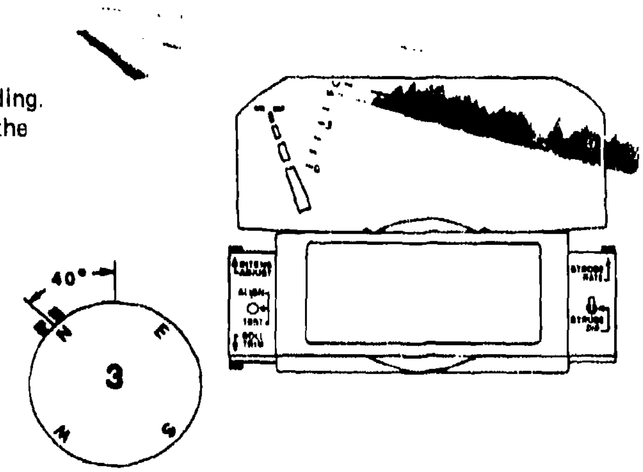
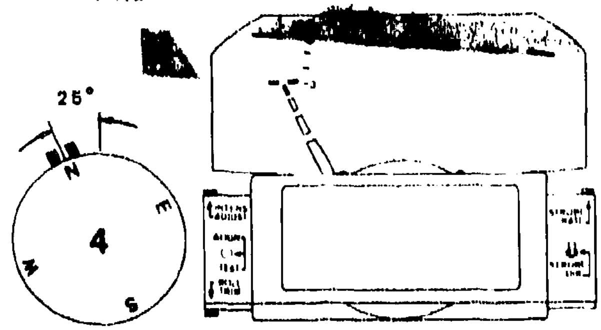


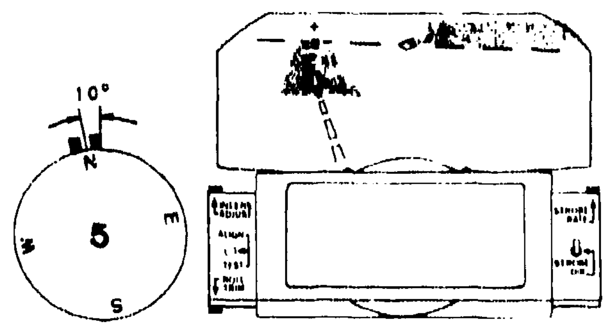
Figure 4. (continued) (sheet 2)

4.

The aircraft has about finished its rollout onto the desired heading. The light-line is strobing away from the aircraft, indicating that the airspeed is higher than the reference, i.e. the angle-of-attack is less than the reference. The heading error is 25 degrees; the displayed lateral error is 10 degrees; in limit the roll attitude is 5 degrees. The pilot notes that he is approximately on heading but offset.



5.
The Pilot reduces bank angle further and notices the bar moving steadily onto the runway. The pilot picks his aiming point and holds the bar there. The throttle is adjusted to hold the velocity vector strobing stationary.



6.
The aircraft is in 0° bank angle and shows a 5° crab to the right because of wind vector, and on proper vector for landing.

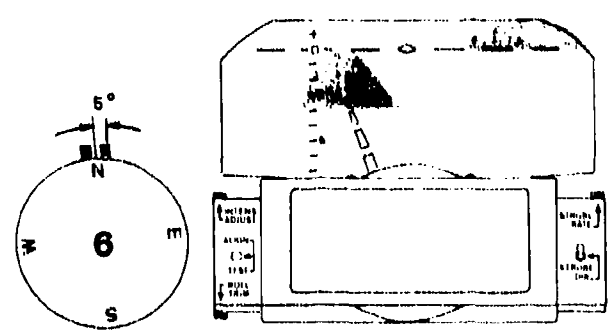
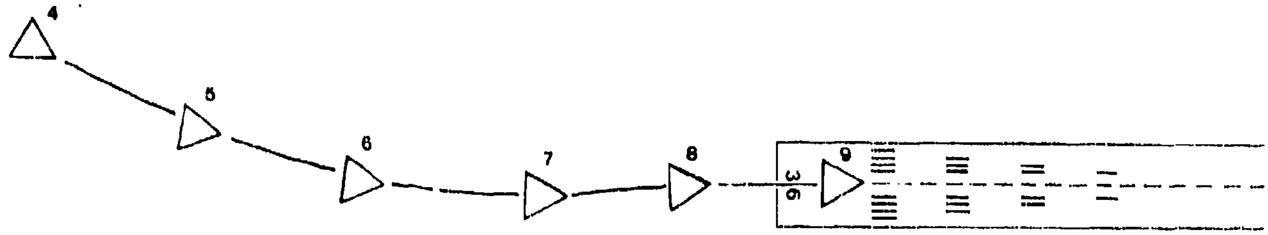
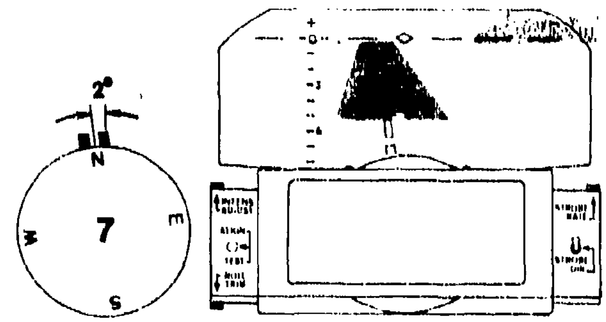


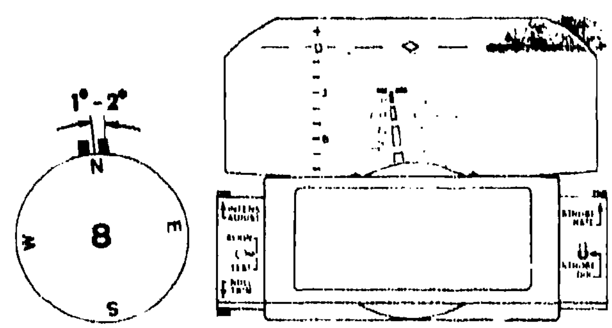
Figure 4. (continued) (sheet 3)



7.
The aircraft is in a 0° bank angle and shows a 2°crab to the right because of wind vector but too far right of runway for touchdown point.



8.
The pilot holds the crab angle and notices the bar moving onto the runway. The pilot picks his aiming point and holds the bar there. The throttle is adjusted to hold the velocity vector strobing stationary.



9.
The pilot is "in the slot". He is on a 1° heading, crab aligned with the runway, on speed (angle-of-attack), and at the desired approach slope (-3°). When the pilot arrives at the proper flare altitude he brings the bar up to -2 degrees, retards the throttles, and a smooth flare is initiated.

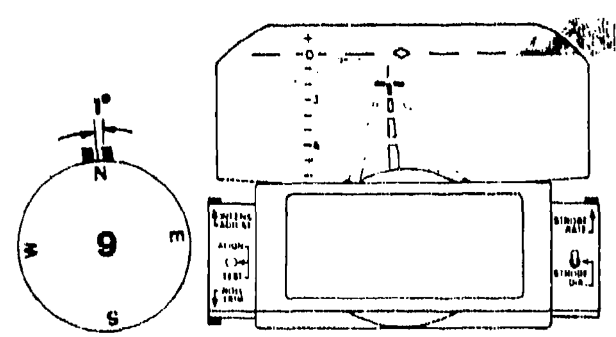
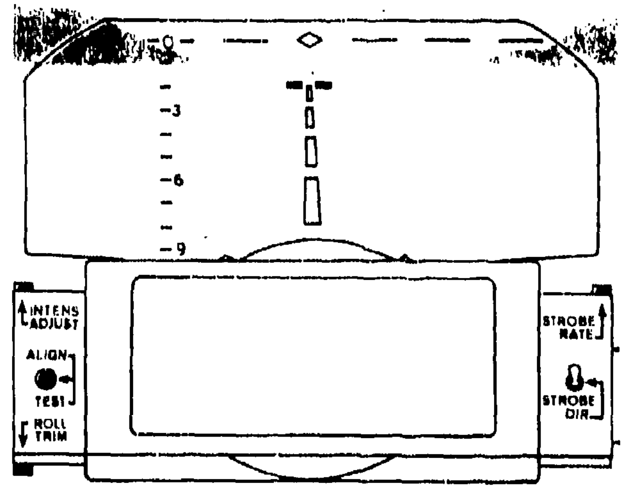


Figure 4. (continued) (sheet 4)

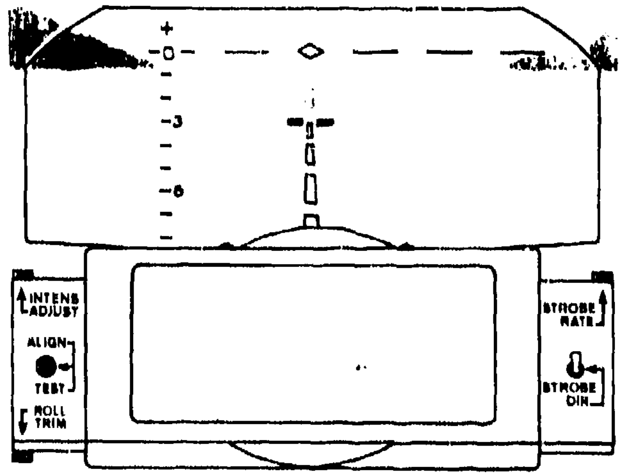
LEVEL FLIGHT – ALTITUDE 4700 FT.

The system is programmed so that in level flight the bar is at -2° as illustrated at the right. Maintaining the flight path bar on -2° keeps the aircraft at a constant altitude. The zero reference on the approach angle scales is slightly above the true horizon by an amount directly proportional to the altitude of the aircraft above the earth. The horizontal line is the extended aircraft horizon. The earth horizon is below the extended horizon because of the earth's curvature. Note that the velocity vector strobes toward the runway (polarity in normal position). Adjust the strobe rate control to a comfortable setting.



-3° APPROACH ANGLE – 5 N.M., ALTITUDE 1500 FT.

The adjacent illustration shows the aircraft descending toward the runway from 5 N.M. out. From this point, continue the approach and maintain the bar on the TDZ with adjustments of pitch and thrust. At this distance it is satisfactory to keep the bar within the first half of the runway.



-3° APPROACH ANGLE – 3 N.M., ALTITUDE 900 FT.

Wind shears may cause the bar to move off the aiming point, indicating that the aircraft is descending long or short of the TDZ. Maneuver the bar back to the TDZ. These thrust and attitude changes are the same as those performed during the normal "eyeballed" approach. A corresponding change in the strobe rate will be noticed depending on the wind shear direction at the same time that the bar moves off of the TDZ. At this altitude the bar should be somewhere on the first third of the runway.

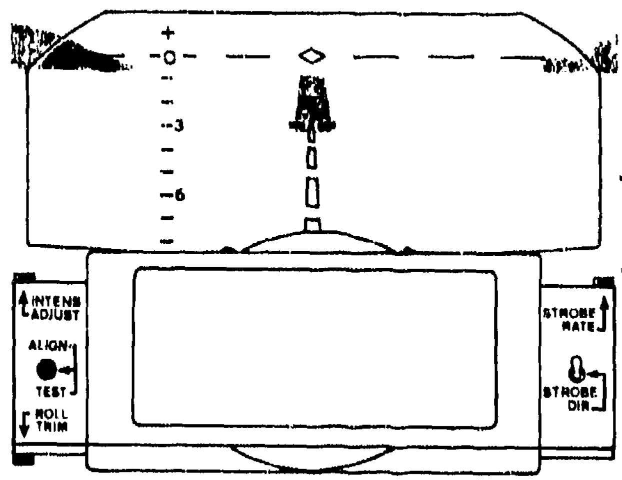
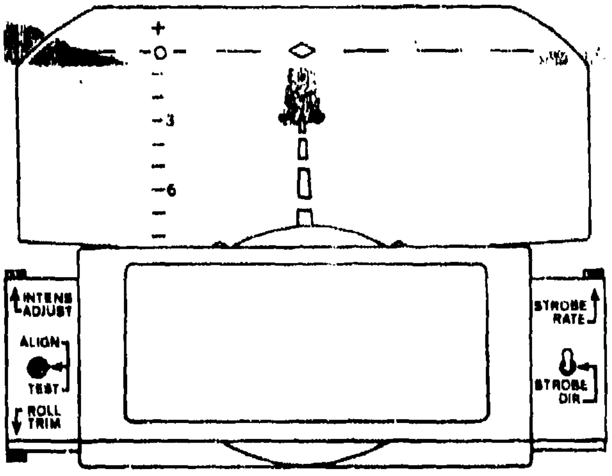


Figure 5. Director Mode. (sheet 1)

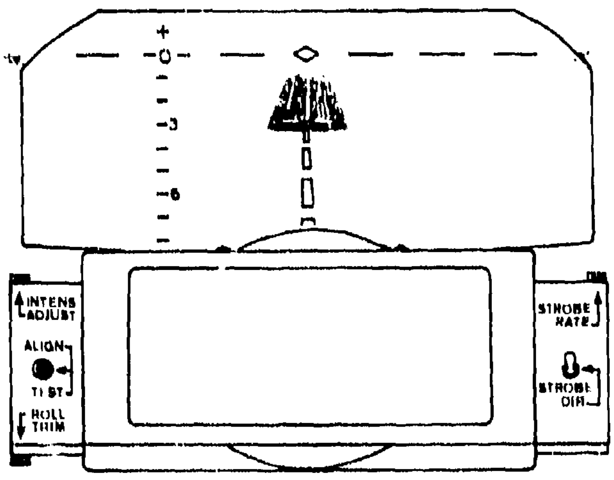
-3° APPROACH – 2 N.M., ALTITUDE 600 FT.

At this altitude the aircraft should be in the final landing configuration and in the slot ready for landing. The airspeed should be on V reference plus the margin speed. The sink rate should be established at the desired rate. From here on in the pilot should be a systems monitor. Every flight parameter should be stabilized.



-3° APPROACH ANGLE – 1/2 N.M., ALTITUDE 150 FT.

The final portion of the approach is illustrated in 1/2 N.M. and an altitude of 150 feet. The aircraft is "in the slot" and requires only minor adjustments to pitch and thrust. The flight path bar should be placed on the desired touchdown point, and the normal scan pattern should be continued.



-2° APPROACH ANGLE –
OVER THRESHOLD, ALT. 30 FT.

The flare maneuver is initiated, the flight path bar is slowly raised to the -2° mark breaking the sink rate. After several approaches the proper flare angle can be determined and a smooth precise flare maneuver performed.

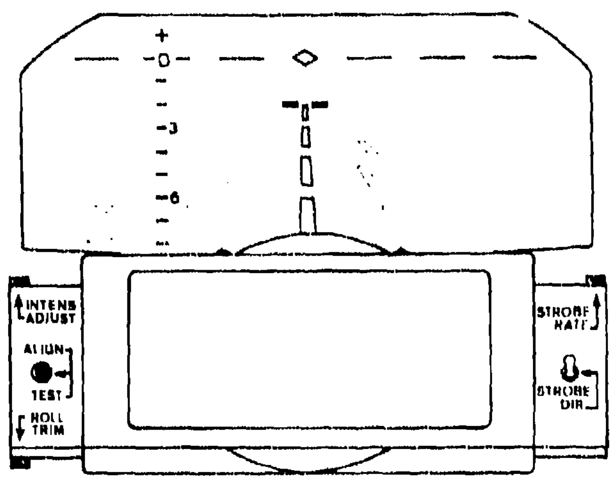


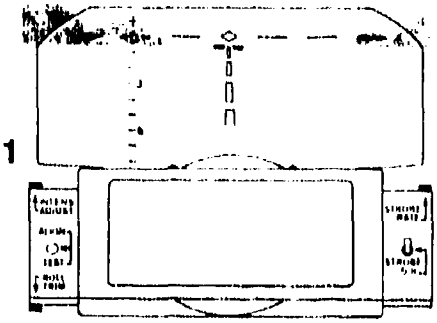
Figure 5. (continued) (sheet 2)

DISPLACEMENT MODE γ

STRAIGHT-IN APPROACH
NO WIND, ON HEADING

LEVEL FLIGHT

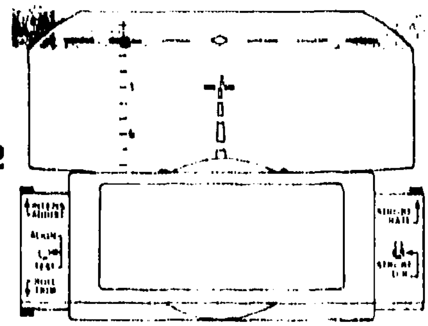
1



The system indicates instantaneous flight path, all illustrated below. Maintaining the bar on the horizon line keeps the aircraft level and at a constant altitude.

-3° APPROACH ANGLE -- 10 N.M., ALT. 3100 FT.

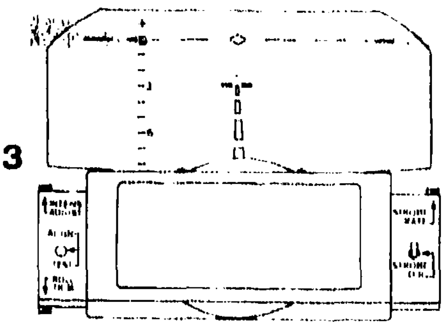
2



To fly the γ mode the scale indicator is the primary information. The first task is to align the scale with the TDZ. Wait until the -3° scale mark lines up with the runway and pitch the aircraft. The illustration indicates that the desired approach slope has been reached.

-3° APPROACH ANGLE -- 9 N.M., ALT. 2700 FT.

3



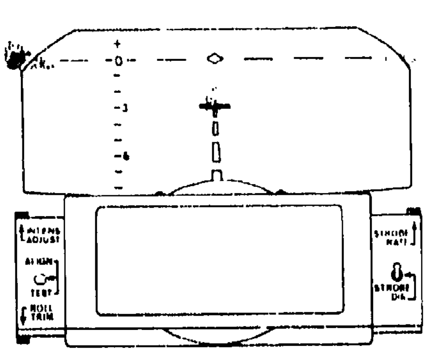
The primary task is to align the scale by pitch and thrust to maintain it at -3° on the runway. The TDZ appears to be offset from the desired slope; a -3° slope is indicated as illustrated to the right. This means that the pilot is above the desired flight path. To intercept the desired slope the pilot must aim short of the desired TDZ for a period of time. If the pilot flies a -5° slope he will eventually intercept the desired -3° slope. The runway appears to rise in the display; when the TDZ is opposite the desired slope the flight path bar is raised onto the runway.

Figure 6. Displacement Mode. (sheet 1)

-3° APPROACH ANGLE – 4 N.M., ALT. 1200 FT

The runway TDZ again appears offset from the desired approach slope. The slope is -2.5° to the desired TDZ. To get back onto the desired slope the pilot aims long of the TDZ. The runway will appear to drop on the display; when it intersects the desired -3° slope the bar is placed on the TDZ.

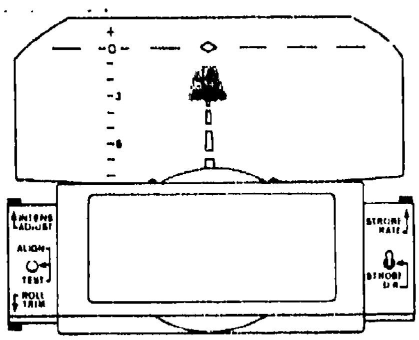
4



-3° APPROACH ANGLE – 1 N.M., ALTITUDE 300 FT.

The runway TDZ is opposite the -3° scale mark and the flight path bar overlays the TDZ. The aircraft flight path would appear as straight line segments steeper and shallower than the desired -3° slope. The vertical tracking task is considerable to fly a precise angle to the TDZ.

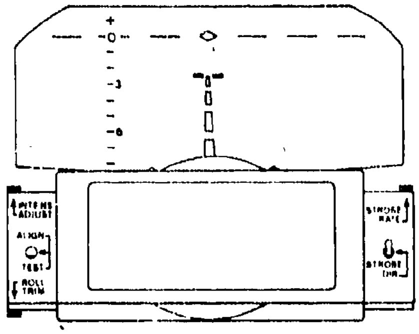
5



-2.5° APPROACH ANGLE – OVER THRESHOLD, ALTITUDE 30 FT.

The flare maneuver can be executed smoothly by slowly bringing the flight path bar up to -1 to -1.5°.
With experience the exact angle for flare can be determined and a smooth touchdown made consistently.

6



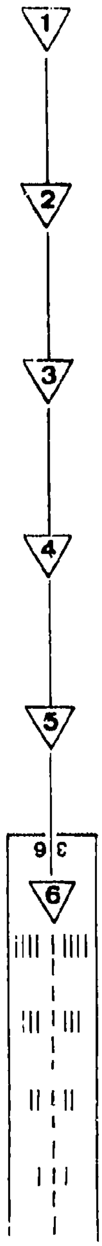


Figure 6. (continued) (sheet 2)

RESULTS AND DISCUSSION

The Light-Line HUD evaluation was accomplished to meet two separate, but interrelated objectives. The profiles flown during the evaluation were designed to investigate the acceptability of the Light-Line HUD as a visual landing aid and to determine the conceptual merits of using this type system in a dynamic environment, that is, air-to-air, air-to-ground target acquisition/tracking, etc. Each section of the results is presented separately; however, the findings are interrelated.

Twelve subject pilots participated in this evaluation. The test plan called for each pilot to fly four separate sorties and accomplish specified maneuvers; however, due to equipment problems, adverse weather conditions, and traffic congestion, each pilot was not able to perform all maneuvers specified. Additionally, some pilots responded to some questions even though they had not flown those maneuvers. Therefore, the total subject responses for each maneuver may or may not always equal twelve.

Subject pilots were asked to compare non-HUD performance (visual approach) with the two modes (director and displacement) of HUD operation during standard VMC straight-in approaches, visual overhead approaches and IMC approaches. The questionnaire is divided into three areas. The first area relates to the overall usability of the HUD for approaches and landings including touchdown precision, problems during IFR transition, workload, flightpath control, flightpath precision, and speed control. The second area covers HUD symbology such as flightpath scale, speed and heading deviation, etc. The third area (section two) covers the conceptual aspects of the HUD. The following text presents pilot responses and highlights pertinent problems brought out by either the subject or project pilots during the flight evaluation.

SECTION I - LIGHT-LINE HUD AS A LANDING AID

The most difficult visual tasks associated with flying a non-HUD visual straight-in approach, as identified by subject pilots, are acquiring and maintaining a desired glide path angle. High approach speeds, high angles of attack, and changes in aircraft sensitivity (control feel and effectiveness), when in the landing configuration, contribute to problems in maintaining flightpath consistent with a desired aim point. In flying overhead patterns, the pilot is not only tasked to determine and fly a flightpath to an aim point on the runway similar to a straight-in, but he must also determine the aim point and establish the glide path during close-in turn to final. Task difficulty, therefore, is increased since the aircraft descends in a turn at a high rate (1500 - 2000 fpm). As the pilot rolls the aircraft out on final, he is tasked with determining a desired flightpath to an aim point, maintaining alignment with the runway and simultaneously reducing his airspeed to final approach speed. His workload increases during overhead patterns as a function of turn radius, altitude loss, etc. The roll out to final is normally 1 to 1-1/4 miles from runway threshold thereby requiring the pilot to stabilize parameters within a very short time period (approximately 20 seconds). Therefore, the overhead pattern has some unique problems of its own, in addition to those associated with straight-in approaches.

Only one subject pilot considered the Light-Line HUD adequate for straight-in VFR approaches in little, if any, turbulence or crosswind conditions. Seven of eight pilots, who responded, stated that the Light-Line HUD did assist them in performing the various tasks associated with straight-in approaches. Only five of ten subject pilots that responded considered the Light-Line HUD to be of any assistance in the overhead pattern. The lack of assistance in the overhead pattern may have been due either to the decreased time involved when flying an overhead pattern or HUD display mechanical limitations. (Mechanical limitations will be discussed later in this report.)

Five subject pilots flew approaches in IMC where they utilized the Light-Line HUD to transition from instrument conditions to a visual approach. Two of these five pilots said that the Light-Line HUD assisted them in transition to a visual approach; however, the information displayed was insufficient to maintain total "heads-up" after breaking out of the weather. (Project pilots interpreted this to be caused by the difficulty in interpreing airspeed (angle-of-attack), and the lack of altitude and range information.) All five pilots said the assistance gained from the HUD reduced the time required to establish and maintain the proper glide path and aim point to the runway.

Ten out of eleven subject pilots considered the light-line director mode as producing a more precise overall straight-in visual approach compared to a non-HUD visual approach or in the displacement mode. The Light-Line HUD "velocity vector," being focused at infinity and actually providing an automatic commanded approach, may be the reason for the overwhelming majority preference for the director mode. The automatic command to a preselected flightpath angle closely relates to the standard flight director command steering bars. Thus the pilot had only to align the light-line (wand) with the desired aim point to maintain the desired glide path.

Overall precision when comparing the three methods of flying the overhead approaches was split three to three between the normal no-HUD and HUD director mode. One pilot considered the HUD displacement mode as superior but did not explain why.

As stated previously, only five pilots had an opportunity to fly the Light-Line HUD during missions which permitted them to transition from actual IMC to VMC for landing. Four of the five pilots felt the director mode provided more precision after transitioning than either the displacement or no-HUD condition.

As the pilot transitions from enroute to the terminal area, he is tasked with flying precise instruments. When flying in weather with the aircraft configured for landing (gear and flaps down), the pilot is required to fly precise airspeed and maintain a constant glide path as well as flying precise headings. The subject pilots noted their workload while flying each of the three methods - no-HUD, director mode, and displacement mode. Flying the HUD director mode was generally rated lower in workload than either the no-HUD condition or displacement mode. The greatest overall difficulty occurred during straight-in approaches, with the director mode being rated as having the lowest workload, followed by displacement mode and no-HUD.

The pilots again stated that when flying overhead patterns the director mode produced a workload slightly less than no-HUD visual patterns and the displacement mode produced the highest workload. Subject pilots who flew in weather conditions and then transitioned to VFR rated their workload basically the same as the overhead approaches; that is, director mode had the lowest workload followed by no-HUD and displacement mode.

Maintaining a constant glide path to a desired aim point helps to decrease pilot workload. The use of the Light-Line HUD appears to have augmented the pilot's ability to maintain a more precise constant flightpath to an aim point during straight-in approaches. Nine subject pilots considered their ability to fly a specific constant flightpath from a straight-in approach to have been superior utilizing the director mode while two pilots rated the displacement mode as superior compared to the other methods flown. For overhead patterns, it appears that the Light-Line HUD did not assist the pilots as much as anticipated as evidenced by seven pilots stating they could establish and fly a superior flightpath visually (no-HUD). Only three pilots rated the use of the HUD director and displacement modes superior. The apparent lack of usefulness evidenced by the no preference for the HUD during overhead patterns may have been due to a unique problem causing a lag of the velocity vector (wand). It is not known whether the HUD system was accepting precession errors from the gyro platform or if the computer/light-line mechanization produced a lag in the system. Nonetheless, the pilots commented that the wand was not providing the proper indications and thus the pilot could not effectively use the wand to fly a desired flightpath to the runway after the aircraft rolled out on final.

Project pilots noted by the time the wand was responding properly, the aircraft had traveled to within 1/4 to 1/2 mile from touchdown. Had the pilot attempted to use the wand at this time, the aircraft would have leveled off. After the lag errors were reduced or eliminated the wand indicated properly. If the pilot adjusted pitch/power to place/maintain the wand on the desired aim point, the aircraft would be descending at a higher than desired flightpath angle resulting in a high sink rate. Thus the Light-Line HUD during overhead patterns produced a stair-step final which was not acceptable.

The ability of the pilot to transition from IMC to VMC and to establish a constant flightpath to an aim point was easier when utilizing the director mode. Five subjects rated this mode superior in flying a desired flightpath while three pilots rated the no-HUD method superior.

A constant glide path enhances the probability of the aircraft landing within a specified zone. Therefore, the closer the pilot can maintain a desired glide path the better the chances for a constant touchdown point. Aircraft touchdown precision was considered best when utilizing the director mode by six of eleven subjects. However, four pilots rated the visual no-HUD approach as best while only one subject felt the displacement mode best. Again, during the overhead pattern, seven subject pilots considered the visual no-HUD approach provided the best touchdown precision. Only two subjects considered the director mode best and two selected displacement mode best.

Touchdown precision after transitioning from IMC to VMC was considered best when flying with no-HUD by five subject pilots while three subject pilots considered touchdown precision best when using the HUD director mode. No comments were given on the displacement mode.

Although there appears to be a contradicition between the best method of obtaining a constant touchdown point, it may be partly due to the following. When using the director mode after breaking out of the weather, transition to the desired glide path as commanded by the HUD system is a more gradual change and; therefore, the automatic command did not help the pilot transition to the standard technique for landing in the first 1000 feet. When flying a standard instrument approach, the ground point of interception is between 750 - 1500 feet down the runway. However, the T-38 procedure for landing is to transition to an aim point half-way into the overrun to ensure the touchdown point is within 1000 feet of the threshold. During a visual approach the initial pitch and power changes are normally greater than those directed when using the HUD director mode; therefore, more time is available when maneuvering the aircraft visually to stabilize on the desired glide path which could result in a more precise touchdown within the first 1000 feet. Therefore, it is the project pilot's opinion, if landing techniques had been different (that is, the aircraft is flown down the normal ILS glide path to GPIP), results of the ratings may have been different.

Procedures for flying a visual straight-in approach normally places the aircraft on a 5-mile final. The pilot will fly the aircraft at a specified altitude to a start descent point. Subject pilots stated they were able to use the HUD information during straight-in approaches at a distance of 2-1/2 NM from the runway out to approximately 8 NM. Six pilots stated they were able to use the HUD information consistently between 3 to 5 NM from the runway. Project pilots and several subject pilots indicated that the light-line would command a descent prior to reaching the normal visual straight-in descent point when flying in the director mode. This appears to have been caused by the designed mechanical placement of the wand at 2° FPA when the pilot selected 3° FPA. As the aircraft approaches the runway and the wand reached the desired aim point the pilot would adjust pitch/power to maintain the wand on the aim point, thus the aircraft would initially descend at a 2° FPA. Thereafter the computer would command the pilot to fly the aircraft to correct to the desired 3° FPA. Initial altitude for use of the displayed information ranged from 500 feet - 3000 feet AGL with four subjects stating that they could consistently use the information effectively between 900 - 1000 feet AGL. Even though the light-line wand travel was $\pm$ 9.5° from the heading selected (that is, runway centerline), the pilots indicated initial azimuth use ranged from on the runway to $\pm$ 20 - 30°. Subjects did not state the specific type information obtained from the HUD during the time the wand was stowed (when the heading error was greater than 9.5° from the heading selected on the HSI).

The overhead pattern revealed some unique problems when using the Light-Line HUD. Six pilots stated they could not begin to use the HUD information until the aircraft had rolled out and stabilized on final. Other individual pilots stated initial use of HUD information began between 1/2 to

1 NM; 500 feet AGL and during the last 30° to 45° of final turn. However, these individuals did not state the specific information derived from the HUD during the last 30° to 45° of turn.

At this point in the discussion it may be necessary to address what appears to be a direct contradiction expressed by the subject pilots. The light-line was considered unacceptable for use in Air Force aircraft yet provided some improved performance over the no-HUD conditions in areas such as workload, flightpath angle, touchdown precision, etc. What has been presented thus far has been dealing with overall general areas of pilot consideration. In certain respects, the light-line was a definite aid and did improve performance; however, this improvement was not across the board for all approach types under all conditions evaluated. Taken together with individual problem areas associated with the light-line, as discussed below, the reasons for the general unacceptability will become more apparent.

The displayed information was considered unusable during parts of the final approach by six subject pilots. During the glide path break (flare initiation), flare, and touchdown, three pilots said the information could not be used and the HUD got in their way. However, no explanation was given nor the exact problem indentified. Approaches during crosswind conditions presented unusual problems in interpreting the speed error. When flying in a crab with the heading constantly changing, it was extremely difficult to maintain the proper aim point with the wand.

The light-line was thought to aid clearing and reduce heads-down time by seven pilots; however, there were times when they tended to focus their attention around a 60° cone directly around the Light-Line HUD. The light-line was not an aid to clearing for five pilots primarily because their attention was shifted due to the distracting effect of the artificial horizon displaced from the true horizon. Additionally, they tended to focus on the display rather than look through it. Most of the display elements; flightpath scale, bar symbol, and artificial horizon line were considered easy to read and interpret as individual elements by most of the subject pilots. The speed error, however, was considered difficult to interpret by seven of nine subject pilots. Problems relating to the speed error will be discussed separately below since a large part of the dissatisfaction with the light-line was related to this one display element.

Response of the bar symbol (transverse bar) to control inputs was thought to be both prompt (8 to 3) and accurate (10 to 1) in both modes of operation. However, two negative features were pointed out; a significant lag in pitch response and a slow response on leveloff at all altitudes after high rates of climb/descent and roll out on final from an overhead approach.

The selected approach angle in the director mode was properly commanded according to 10 subject pilots. On two occasions the command was not considered to have been properly executed; however, this was subsequently traced to a malfunction in the HUD system. The light-line computer was returned to Sundstrand, repaired and reinstalled.

In the displacement mode, alignment of the bar symbol with the desired approach angle on the flightpath scale was easily accomplished by seven of 11 pilots and with adequate precision by 10 of 11 pilots. Once alignment was obtained, holding the bar symbol on the scale was considered easy by eight of 11 pilots and with adequate precision by seven of 11 pilots. Although this aspect of the displacement mode was rated fairly high by subject pilots, various problems with this method were expressed. As turbulence increased or under crosswind conditions, maintaining the bar symbol precisely on the flighpath scale increased workload. Control inputs necessary to correct for deviations were considered difficult probably because of unfamiliarity with the amount and degree of inputs required to make small corrections. Ten of 11 subject pilots were able to place the bar symbol on their selected aim point; however, only seven pilots stated they could easily hold the symbol there. Difficulty in holding the bar symbol on the aim point attributed to the symbol moving excessively during gusty turbulent conditions and during crosswind conditions where a crab was required. Additionally, the bar symbol was considered too wide to hold on the desired aim point when the aircraft was 3 to 4 miles from the runway, due to the relative size of the bar symbol to the runway. It was also stated that under reduced visibility conditions, it was sometimes necessary to look around the combining glass in order to see the runway. Difficulties with holding the bar symbol on the aim point and aligning the bar symbol on the desired flight-path angle scale were interrelated especially in terms of turbulence and crosswind conditions. While attempting to maintain the wand on the aim point, it would be rather easy for the bar symbol (transverse bar) to deviate from the proper flightpath angle scale thus requiring additional control inputs and mental calculations to adequately determine the required or proper control inputs. It appears that until the subject pilots obtained sufficient experience on use of the light-line under various conditions, the precision required by pilots to fly a good approach would not be obtainable and would result in lowered pilot acceptance of this mode.

A major area of concern regarding the light-line is the presentation of airspeed error via the strobing wand. Although some aspects of presenting speed information in this format were acceptable to subject pilots other aspects appeared to have reduced pilot performance and acceptability.

Speed error was considered easy to interpret by only two subject pilots. Eight pilots said the strobing was confusing for various reasons, including forgetting which direction was fast or slow. During turbulent conditions the wand moved too rapidly causing partial blurring of the symbology. The strobing was basically a qualitative indication of speed error. With sufficient experience pilots could learn to interpret approximately what strobe rate was equivalent to a specific speed deviation. However, with turbulence and crosswind conditions, it became more difficult (if not impossible) to interpret exactly. Additionally, maximum strobe is presented when speed deviation is $\pm$ 8 to 10 knots. Eight subject pilots were not able to determine airspeed when maximum strobe was reached (the strobe rate was at its maximum) and seven stated that a method of presenting airspeed in excess of 10 knots is necessary for safe operation. Without some type of indication when the airspeed exceeded the maximum, the pilot had to go "Heads-Down" and thus reduced the effectiveness of the Light-Line HUD. Eight pilots believed that a "Fast-Slow" (F-S) indication would be sufficient to at least eliminate the problem of not knowing if the maximum displayed speed deviation was being exceeded.

Even with these problems, seven pilots said their approach precision and confidence were enhanced by depicting speed error in the form of a strobing light. Only two pilots considered the strobe method of displaying speed deviation as degrading both precision and confidence. Five pilots considered workload to have been both increased and decreased. These responses indicate that this method of presenting speed error was basically acceptable and indeed useful but due to the problems enumerated previously, additional improvements are required.

The HUD system provides the capability to adjust the (in-line light segments) strobe rate. Only six pilots chose to change the strobe rate, five pilots increased the rate, and two pilots decreased the rate. The pilots who increased the strobe rate said the faster rate was more attention getting and easier to incorporate into their scan pattern.

The HUD system also provides the capability of selecting the direction of strobe to indicate a FAST or SLOW condition. With the toggle switch in the down position, the four in-line segments strobed towards the pilot when the aircraft is flying faster than desired (low AOA) and away from the pilot when low on airspeed (high AOA). When the toggle switch was in the up position, then the reverse would occur; that is, a fast (low AOA) strobe was away, slow (high AOA) strobe was toward the pilot.

Seven subject pilots preferred speed error be represented by the in-line light segments strobing away under low airspeed (high AOA) conditions and toward them under high airspeed (low AOA) conditions. Only three pilots preferred the strobing be away from them for a fast indication. (See descriptions of test item for more information relating to strobe direction.)

Another area of investigation was the light-line's capability to eliminate or reduce the possibility of over or undershoots during the last portion of the final turn during overhead patterns. Ten of 11 pilots stated the flightpath symbol did not assist them in determining either over or undershoots. This was at least partially due to the light-line's small field of view as installed in the evaluation aircraft. The horizontal field of view was considered just right by six pilots and too small by five subject pilots. Seven of 11 pilots considered the vertical field of view as being too small. The $\pm 9.5°$ heading error from selected runway heading was satisfactory for 10 of 11 pilots for straight-in approaches, but satisfactory for only three pilots during overhead approaches. For approaches in turbulent conditions, seven of 10 pilots stated the heading error was satisfactory for strong crosswind landings. The light-line installation was considered to have an uncomfortable viewing position by nine subject pilots. Seven pilots stated the installation was too low; two thought it was too close to the pilot; one thought it was too high; and two did not respond to this question.

The relationship of the heading symbol to the light-line wand was thought to be meaningful by seven of 11 pilots. However, some negative comments were made including oversensitivity of the heading symbol, confusion caused when flying in a crab, and a requirement to align the aircraft with the runway prior to adjusting the heading set marker of the HSI. It must be pointed out that during the evaluation, subject pilots and project pilots observed a significant deficiency in the test bed gyro platform/heading systems which may have caused a negative response to the light-line heading feature. The heading system in the IFC/RD T-38 is susceptable to precession errors which were quite evident when flying an ILS approach. When the aircraft was properly aligned and the precession errors in the heading system caused the HSI to be off from the desired heading, the wand would also be displaced left or right of the runway aim point by the number of degrees of precession in the heading system. If the pilot attempted to use the HUD with the heading error, then the aircraft would depart from the desired course to the runway. To correct this deficiency, pilots were told to readjust the heading marker on the HSI to move the wand to the desired aim point. This correction on the HSI was also necessary during visual straight-ins and overhead patterns; thus, the pilot had to perform another manual operation to use the system effectively. It appears the pilot's acceptance of the heading feature may have been reduced due to this problem. Again it is very probable that at least some of these problems would be eliminated if the proper design installation could have been obtained or if a more stable gyro platform had been installed in the test bed.

With the heading inhibited (the wand held stationary with aircraft heading) no significant degradation in performance was noticed. Under this condition, level turns were easier to fly and maintaining the light-line on the aim point during straight-in approaches was somewhat easier in zero or very light crosswind conditions.

Seven of 11 subject pilots did not encounter problems of flying through the flare point when using the light-line. Of the four pilots who encountered this problem their reasons were stated as fixation/distraction by the HUD symbology or distraction by the collimating glass itself, although no further explanations were provided. This problem was probably due to unfamiliarity with HUD systems; that is, looking at the HUD rather than through it. In order to avoid any potential problems during the flare, seven pilots stated that a flare cue was required for landing. Preoccupation with the HUD to the exclusion of the outside environment was encountered by six pilots. This problem appeared to be basically common until the pilots had gained experience with a HUD.

The light-line symbol (transverse bar) was the only illuminated element to have obscured any outside cues. Two of 11 pilots stated that the bar was too large and therfore, obscured the runway touchdown zone when the aircraft was further than 5 miles from the runway. The illuminated elements of the light-line did not obscure or mask any outside cues during night operations. The reverse, outside lights at night, not obscuring illuminated elements was also true. The intensity adjustment for the illuminated elements was considered inadequate by six pilots. Under high light level conditions, the tip of the wand (transverse bar) could not be seen. Additionally, the automatic photoelectric intensity adjustment was considered adequate by only half of the subject pilots.

Three of 11 subject pilots observed some distortions near the edges of the combining glass during flares and climbs. One pilot stated during the final portion of the approach the runway appeared to be farther away than it actually was. Objectionable vibrations and/or oscillations were noticed by three subject pilots during takeoff. However, as noted by all pilots during debriefings, the HUD was not usable during the takeoff roll. Such problems as the wand twitching and drifting with no apparent change in aircraft headings were mentioned but can be attributed to mechanical or electronic problems and not to HUD vibrations.

Light-line control operation was satisfactory for all pilots and nine of 11 subject pilots considered the controls visible and readable under all the ambient light levels encountered. However, project pilots noted that the lighted portions on the control console were too bright and caused considerable distraction in the cockpit during night operation. Therefore, a dimmer switch for the control console should be installed for night operations.

Light-line failure is indicated by having all display symbology extinguished. This method was thought to be satisfactory by seven of 11 pilots. However, one pilot commented that if possible only the failed or erroneous information should be extinguished. Only three pilots wanted another method of failure indication. One pilot stated that some other method should be used so the pilot would not spend time looking for symbology upon failure. Although the situation is probably remote, it could occur in bright sunlight where the pilot might think that the symbology was washed out rather than failed.

In summary it appears from the opinions of the subject pilots that problems associated with individual light-line elements and certain design deficiencies resulted in an overall unsatisfactory rating for the Light-Line HUD. Despite the varied problems expressed by the pilots, the workload, overall approach precision, flightpath precision and touchdown precision were generally rated as superior in the director mode for straight-in approaches as compared to the displacement mode and no-HUD conditions. The problems associated with turbulence, crosswinds, overhead and approaches under IMC underlie the basic deficiencies associated with the light-line. The available information and presentation method are marginally satisfactory for straight-in visual approaches in high performance aircraft. Once the straight-in approach was established, the light-line information was sufficient to aid the pilot during a visual landing; however, if turbulence or crosswinds were encountered, the light-line usefulness was degraded to a point that maintaining proper airspeed, heading, and aim point became increasingly difficult. These problems not only reduced the usability of the light-line but also required additional "Heads-Down" time in order for the pilot to obtain the correct flight information.

Since speed deviation had a maximum range of ± 8 to 10 knots, pilots did not have adequate display of speed error information if this range was exceeded. This required the pilot to go "Heads-Down" to ascertain their actual airspeed.

Overhead approach and IFR transition approaches compounded the problems associated with straight-in approaches. The heading deviation of $\pm 9.5°$ did not allow effective utilization of the light-line throughout the final turn. Either outside visual cues or cockpit instruments had to be used to obtain airspeed, heading, and aim point information. It was generally agreed that by the time heading error and airspeed deviation became useful, the aircraft was too close to the runway to effectively use the light-line. If the breakout occurred early enough during approaches in IMC, the light-line could be used much the same as with straight-in apporaches. However, during the IMC phase of the approach, insufficient information in relation to heading, pitch and bank, and airspeed was provided to the pilot on the HUD. The pilot could not use the light-line in a manner as to consider the approach as being truly "Heads-Up." A note must be made here that the HUD was designed as an austere HUD to be used as a visual landing aid during straight-in approaches. To some degree, it appears that the HUD was useful, but additional investigation/modifications must be performed on the system to enhance its usefulness as an overhead visual landing aid.

SECTION II - LIGHT-LINE CONCEPTUAL EVALUATION

This section presents the results of the Light-Line HUD in operations other than approaches and landings. Some of the maneuvers and parameters were simulated during the test flights. Other areas were purely theoretical questions based on pilot experience with the light-line.

As presently configured, the light-line could be utilized for tracking of ground targets with the displacement mode; however, only five subject pilots thought that this task could be satisfactorily performed in the director mode. In terms of accuracy, opinions were approximately evenly split between those pilots who thought light-line would be better or worse than an open gunsight reticle.

Maintaining level flight at both high and low altitude was considered to be adequate with the displacement mode by a 10 to two pilot majority. With the director mode, this flight operation was considered adequate by eight subject pilots. (It must be stated that due to the design, the wand was positioned at -2° when selecting director mode, thus the pilot flew the HUD with an indicated -2° FPA for level flight.)

Eleven subject pilots stated that a constant heading could be satisfactorily maintained during level flight. Five of these pilots considered the maximum accuracy to be within $\pm 2°$. The wand was still considered to be too sensitive and a good gyro platform was a necessity to adequately perform this flight function. Nine subject pilots thought that the light-line could be used to clear high level obstructions, but did not state which mode was best.

If a slewing capability was incorporated on the heading marker, the majority of subject pilots believed that the light-line could be utilized to direct the aircraft to a new heading. However, to accomplish this, the available lateral movement would have to be increased. Subject pilots requested that the lateral range of travel of the wand be from ±20° to greater than ±35°.

The light-line could be used for turn maneuvers; however, some modifications were suggested, including addition of pitch and bank information and command steering.

In the displacement mode, all subject pilots stated the light-line could be used for climbs and descents at a constant flightpath angle. A majority of the subject pilots agreed that performance of the maneuver would be easier if the wand strobing corresponded to actual airspeed rather than AOA derived speed deviation.

Tracking of airborne targets was thought possible; nevertheless only two subject pilots believed that the light-line could be utilized for either formation join-ups or air refueling without modifications The only aspect of the light-line considered helpful for in-flight refueling was the speed deviation presented by the strobing wand.

Half of the subject pilots did not know if the light-line could be used for in-flight recovery operations. The subject pilots stated that it either could not be used or could be used only in as much as a flight vector could be presented to the pilot.

Subject pilots indicated that major modifications were required before the system could be used in air-to-air combat role, as a weapons delivery system or in a low level navigation role. Their recommendations are presented later in this report.

The potential advantages of the light-line in areas other than landings can be ascertained from the pilots' opinions concerning the conceptual evaluation. It was thought that some tasks such as, tracking of ground targets and maintenance of level flight with a constant heading could be accomplished to varying degrees of acceptability with this Light-Line HUD.

It appears that the light-line should be redesigned and/or modified to improve its capability in performing the above tasks and enhance its usefulness during weapons delivery, air refueling, and air-to-air combat maneuvers.

CONCLUSIONS

1. The Light-Line HUD, as presently designed, is unsatisfactory for use in US Air Force aircraft. However, as a result of the evaluation, various advantageous features were enumerated by subject and project pilots. These features appear to warrant further development for use as a landing aid and in other areas of the flight regime.

2. The director mode, when used during straight-in approaches, reduced pilots' workload and increased the precision of the overall approach, including flightpath angle and touchdown, when compared to the no-HUD and displacement mode approaches.

3. Visual no-HUD overhead approaches were generally rated superior to or at least equal to the HUD conditions for the above parameters.

4. Pilot acceptance of the HUD during IMC to VMC transition approaches was mixed depending on the distance from the runway when the aircraft broke out of the weather. The closer the aircraft was after transitioning to VMC, the less the pilot acceptance.

5. Turbulence and crosswinds reduced the usability of the HUD due to the effects of crabbing, wand vibrations, difficulty in maintaining the aim point, and speed deviation (angle-of-attack) parameters of the HUD.

6. Speed deviation in the form of a strobing wand was well received. However, the single strobing cue to show the maximum airspeed deviation of ± 10 knots did not provide the pilot sufficient information. The pilot only knew that his airspeed was off by 10 knots or more but could not determine his exact airspeed.

7. The lateral movement of the wand ($\pm 9.5°$ from selected runway heading) was inadequate for overhead patterns, IFR transition and visual straight-in approaches when flying in turbulence or crosswind conditions.

8. The flightpath scale was well received, but an additional scale was requested.

9. A common phenomenon inherent with HUD systems appears to have been of some concern to the subject pilots. The displacement of the artificial horizon above the real world horizon was considered distracting.

10. The wand and aircraft heading symbol was considered too sensitive due to turbulence, vibration, and gyro precision.

11. The HUD displayed insufficient flight information to be considered a true "Head-Up" display for the different approach types.

12. The transverse bar (end of wand) was considered too large and obscured the runway touchdown zone when far out from the runway.

13. The intensity of the HUD symbology was considered inadequate for bright sunlight and clouds.

14. An apparent lag in pitch response of the wand was considered unsatisfactory.

15. Failure indication was considered adequate; however, some improvements were recommended.

16. Tracking of ground targets was satisfactory in the displacement mode but not in the director mode.

17. Maintenance of level flight and a constant heading were considered satisfactory in both light-line modes.

18. The lateral movement of the wand was insufficient for heading changes, formation join-ups, and air refueling.

19. Speed deviation was considered a possible aid for air refueling (only if pilot had the capability to set desired airspeed).

20. As configured, the light-line could not be used for air-to-air combat roles, a weapons delivery system, a low-level navigation system, or an air recovery role. However, it could be utilized for high-level obstruction clearance.

21. Subject pilots preferred speed error be represented by the in-line segments strobing towards them under high airspeed (low AOA) conditions and away under low airspeed (high AOA) conditions. However, due to the newness of this concept, further evaluations should be conducted on this concept before a firm recommendation is made.

RECOMMENDATIONS

The recommendations presented below represent the observations of the subject pilots and project pilots. These recommendations are presented in two sections (the first deals with the Light-Line HUD as a landing aid, while the second concerns its usage as a more encompassing head-up display).

Section I - Landing Aid Recommendations

1. The Light-Line HUD (although of some assistance for approach precision and reduction of workload) as presently designed is not acceptable as a landing aid. It should not be considered for use in US Air Force aircraft.

2. The advantages of the light-line in assisting pilots during landings warrant further development of the light-line concept.

3. To enhance the acceptability of the Light-Line HUD as a visual landing aid, incorporate the following modifications:

a. The flightpath angle scale should be displayed on both sides of the HUD. This would improve the pilot's scan pattern in that both sides of the display can be used to obtain required FPA information.

b. A "FAST-SLOW" (F-S) indication and/or an angle-of-attack (AOA) indexer should be incorporated to provide the pilot a more common cue for airspeed beyond the ± 8 - 10 knot deviations. However, a digital display of actual airspeed together with the AOA or F-S indication would provide the most useful and versatile information.

c. A vertical and horizontal field of view should be expanded to provide the maximum field of view within limitations of combiner lens/cost. This would expand the HUD capability for overhead approaches and provide usable display information further out from the runway for straight-in approaches.

d. The lateral movement of the wand should be extended to approximately the entire field of view. This would allow utilization of the display information through a greater range of the approach phase.

e. An improved crosswind correction feature should be added so that the aim point can be easily maintained during approaches.

f. Wand sensitivity should be dampened to reduce distracting movement during turbulent conditions.

g. An additional method of failure indication should be added. The present method could be momentarily interpreted as a wash-out from sunlight, clouds, or a highly reflective ground environment.

h. Intensity of the illuminated symbols should be increased. This would improve visibility and reduce wash-out.

i. A flare cue should be added. This would enhance the utility of the Light-Line HUD during the latter part of the approach.

j. The bar symbol should be redesigned (reduced in size). This would reduce obscuration of the aim point.

k. A dimmer should be added in the light-line control panel. This would reduce the light intensity and decrease distraction during night operations.

4. The following modifications should be incorporated to effectively utilize the system during IMC approaches.

a. Selectable course guidance information should be displayed.

b. Pitch and bank information should be provided.

c. Altitude information should be presented to reduce head-down time.

d. Command steering information should be provided.

e. A mode selector to enable the pilot to select the desired information/display configuration.

Section II - Light-Line HUD Conceptual Evaluation Recommendations

These proposed recommendations are those which are believed necessary to increase the versatility and usefulness of the Light-Line HUD outside the landing phase of flight. The areas of flight operations with the proposed recommendations are:

1. All maneuvers:

Drift information.

Angle-of-attack display.

Increased field of view (horizontal and vertical).

Ability to displace wand above and below horizon up to $\pm$ 60°.

Ability to displace wand at least $\pm 45°$ from display center.

Flightpath scale on both sides of display.

2. Air-to-air maneuvers - in addition to those recommended for "all maneuvers":

Indicated airspeed.

Closure rate.

Heading scale.

Pitch and bank scales.

3. Air-to-ground - in addition to those of "all maneuvers":

Dive toss computer.

Indicated airspeed.

Pitch and bank scales.

4. Rejoins, refueling, air recoveries and navigation:

Indicated airspeed.

Heading scale.

Closure rate.

Flightpath scale on both sides of display.

PART I

LIGHT-LINE HEAD-UP DISPLAY

SUBJECT PILOT QUESTIONNAIRE

NAME____________________ Rank_______ SSN_______________

Organization____________________ Duty Phone__________

Date_____________ Flight Time (approx)__________

Flight No. (light line)______________

1. Have you previously flown a "Head-Up" display?

   Yes_____ No_____

   Aircraft(s) _________

   Mission(s) flown _________

2. What is the most difficult visual task <u>without</u> a HUD during each approach below?

   Straight-in approach _____

   Overhead pattern _____

   IFR transition to VFR _____

   a. Did the Light-Line HUD assist in performing any of these tasks?

   Yes_____ No_____

   b. If <u>Yes</u>, which one(s) and how?

3. Using the scale below, please rate your workload for each of the following approaches:

Increasing Workload Difficulty

1 2 3 4 5 6 7 →

	Without Light-Line	Light-Line Director Mode	Light-Line Displacement Mode
Straight-in Visual			
Overhead Approach			
IFR Transition to VFR			

4. In your judgment which was a more precise overall approach?

	Without Light-Line	Light-Line Director Mode	Light-Line Displacement Mode
Straight-in Visual			
Overhead Approach			
IFR Transition to VFR			

5. Where could you effectively begin using Light-Line information?

a. Overhead pattern _____

b. Straight-in approach _____

Range _____

Altitude _____

Azimuth _____

6. Flight path for the below approaches was superior with:

a. Straight-in Visual Approach (check one)

Visual (no HUD)____Director____Display____

b. Overhead Pattern (check one)

Visual (no HUD)____Director____Displacement____

c. IFR Transition to VFR (weather breakout) (check one)

Visual (no HUD)____Director____Displacement____Not Flown____

7. Touchdown precision was best with:

a. Straight-in Visual Approach (check one)

Visual (no HUD)____Director____Displacement____

b. Overhead Pattern (check one)

Visual (no HUD)____Director____Displacement____

c. IFR Transition to VFR (weather breakout) (check one)

Visual (no HUD)____Director____Displacement____Not Flown____

8. At any time during final approach were you unable to use the displayed information to safely control the aircraft?

Yes____ No____

If yes, please explain the circumstances.

9. Did the Light-Line HUD aid you in clearing, i.e., did it provide sufficient information so that "Heads Down" time was significantly reduced?

Yes____ No____

If no, what information was lacking?

10. Were the following display elements easy to read and interpret?

	Read Yes	Read No	Interpret Yes	Interpret No
Flight Path Scale (Protractor)				
Bar Symbol				
Speed Error				
Horizon Line				

b. Please comment on No response(s).

11. In your opinion, did the bar symbol respond promptly and accurately to your control inputs?

	Director Mode Yes	Director Mode No	Displacement Mode Yes	Displacement Mode No
Promptness				
Accurately				

Please explain any No respones(s).

12. In the Director Mode was the approach angle you selected properly commanded?

Yes_____ No_____

If No, what was the approximate error?

13. In Displacement Mode could the bar symbol be aligned and held with the desired approach angle on the flight path scale?

	Aligned		Held	
	Yes	No	Yes	No
Easily				
With Precision				

Please explain No response(s).

14. Was the relationship of the aircraft heading symbol (diamond) and the light-line meaningful?

Yes_____ No_____

If No, why not?

15. In Displacement Mode, were any problems encountered in adjusting speed via the light-line meaningful?

Yes_____ No_____

If No, why not?

16. What effect did the speed error symbology (strobing light) have upon the following:

	Enhanced	Degraded	No Effect
Approach Precision			
Pilot Confidence			
Pilot Workload			

Please comment on "Degraded" response.

17. Did the strobing of the speed error cause any confusion?

Yes_____ No_____

If Yes, please explain.

18. Which direction of speed error was more menaingful for you?

Away from you for Fast _____

Away from you for Slow _____

19. Did you change the rate of speed error strobing?

Not Changed____Increased Rate____Decreased Rate____

Please explain any changes.

20. Were you always able to place and hold the light-line bar symbol on your projected aim point?

	Place	Hold
Yes	_____	_____
No	_____	_____

Please explain No responses.

21. During the last portion of the final turn, did the flight path symbol assist you in detecting potential over/undershoot?

Yes_____ No_____

If Yes, please explain how?

22. Was the field of view of the Light-Line HUD:

	Horizontal	Vertical
Just Right		
Too Small		
Too Large		

If it was not Just Right, what should it be?

23. Was there any tendency to fly through the normal flare point when using the Light-Line HUD?

Yes_____ No_____

If Yes, why?

a. Would a flare cue displayed on the HUD be helpful?

Yes_____ No_____

24. Did you at any time become so preoccupied with the displayed light-line elements as to disregard or forget the outside environment?

Yes_____ No_____

25. The light-line wand strobed at its maximum rate when the aircraft was approximately $\pm$ 8 to 10 knots from the programmed airspeed.

a. Were you able to determine the airspeed/AOA deviation after the strobe rate was at its maximum?

Yes_____ No_____

b. Is it necessary to provide an indication that you have exceeded $\pm$ 10 knots?

Yes_____ No_____

c. If Yes, would a "F" - "S" display for deviation beyond the $\pm$10 knots be sufficient?

Yes_____ No_____

If No, what should it be?

26. Was there any distortion in the collimating (light-line) lens?

Yes_____ No_____

If Yes, please explain.

27. Were there any objectionable motions (vibrations, oscillations, etc.) in the light-line display?

Yes_____ No_____

If Yes, please describe.

28. Was there sufficient range on the intensity adjustment to meet all ambient light conditions encountered?

Yes_____ No_____

If No, please explain.

29. The light-line has an automatic photocell brightness intensity adjustment (after setting the desired brightness with the thumb wheel control). Was this automatic adjustment satisfactory for all ambient light conditions?

Yes_____ No_____

If No, when was it not satisfactory?

30. Did any element of the illuminated light-line display obscure an important area, cue, or light on the runway or adjacent areas?

	Yes	No
Day	___	___
Night	___	___

If Yes, which elements and what was obscured?

a. Did outside lights, particularly runway and airport, interfere with or mask any of the illuminated elements of the light-line display?

Yes_____ No_____

If Yes, what elements of the display were obscured?

31. Did you encounter any problems in the operation of the light-line controls?

Yes_____ No_____

If Yes, which controls, and what were the problems?

32. Were the light-line controls visible and readable under the ambient light level encountered?

Yes_____ No_____

If No, which controls, and what condition?

33. Did the light-line installation allow for a comfortable viewing position?

Yes_____ No_____

b. If No, was the installation:

Too far away _____

Too close _____

Too high _____

Too low _____

34. Light-line failure is indicated by the extinguishing of all display lights. Is this a satisfactory method alerting the pilot of failure?

Yes_____ No_____

a. Should an additional failure indication be presented?

Yes_____ No_____

35. The light-line provides 9.5° heading error from the selected runway heading. Was this 9.5° adequate for:

	Yes	No
Straight-in approach	_____	_____
Overhead approaches	_____	_____
Approaches in turbulence	_____	_____
Large crosswind conditions	_____	_____

Please explain No responses.

36. When the heading error feature was inhibited (light on), the light-line had:

No significant degradation from normal performance _____

Significant degradation from normal performance _____

Please explain your response.

37. Can the light-line be used in segments of flight other than approaches/landings?

Yes_____ No_____

If Yes, which ones?

38. Is the light-line, as you have flown it, operationally adequate and satisfactory for inclusion in USAF aircraft?

Yes_____ No_____

a. If No, what modifications/changes would be required to make the light-line operationally adequate and warrant inclusion in USAF aircraft?

Please return to Major M. Tapia, IFC/RD, Ext 2785

Thank you for your time and cooperation

PART II

LIGHT-LINE CONCEPTUAL DESIGN QUESTIONNAIRE

1. As the Light-Line is presently configured can it be used to track a ground target?

	Yes	No
Displacement Mode	___	___
Director Mode	___	___

a. If Yes, what do you believe would be the accuracy of using the Light-Line for this function?

Same as open gunsight reticle ____

Better than gunsight reticle ____

Worse than gunsight reticle ____

b. If No, to 1, what would be the minimum modifications required to make the Light-Line acceptable for this function?

2. Can the Light-Line be used to maintain level flight?

	High Altitude		Low Altitude	
	Yes	No	Yes	No
Displacement Mode	___	___	___	___
Director Mode	___	___	___	___

a. If No, what additional symbology would be necessary to use the Light-Line for this function?

3. Could you use the system to maintain a constant heading during level flight?.

Yes ____ No ____

a. If Yes, with what degree of accuracy?

b. If No, what other information (symbology) is necessary?

4. If slewing capability was available on the heading marker could the Light-Line be used as a director to a new heading?

Yes ____ No ____

a. Could this function be utilized if the lateral movement of the wand on the combining glass was increased to:

	Yes	No
± 20°	___	___
± 30°	___	___
± 35°	___	___
Other	___	___

5. Could the Light-Line be used to perform turn maneuvers?

Yes ____ No ____

a. If Yes, how would it be used?

b. If No, what changes would be required to perform such maneuvers?

6. Can the Light-Line displacement mode be used to climb or descend at a constant flight path angle?

Yes ____ No ____

a. Could such maneuvers be performed easier if the Light-Line strobing corresponded to actual airspeed?

Yes ____ No ____

7. Could you use the Light-Line to track an airborne target?

Yes ____ No ____

8. Could the Light-Line be used in some stage of a formation join-up?

Yes ____ No ____

a. If Yes, which stage(s) and how?

b. If No, what modifications would be required to effectively use the Light-Line during a formation join-up?

9. Could this Light-Line concept be used to aid the pilot during rendzvous for air refueling?

Yes ____ No ____

a. What modifications/changes would be necessary so that the Light-Line HUD could be used for in-flight refueling?

b. Which aspects of the Light-Line would be most helpful for in-flight refueling?

10. Would the Light-Line as configured, be useful for in-flight recovery operations, i.e. drone recovery?

Yes ____ No ____ Partially ____

a. How would you use the Light-Line for in-flight recovery operations?

11. Could the Light-Line be used to clear high level obstacles such as clouds, mountains, etc?

Yes ____ No ____

12. What modifications are required so that the Light-Line can be used in an air-to-air combat role?

13. Would the airspeed strobe display be useful with a weapons delivery system?

Yes ____ No ____

If No, can you think of any other uses for the strobe concept?

14. Would the Light-Line HUD assist in low level navigation? Consider all aspects, holding precise heading, obstacle clearance, etc.

15. Are there any other operations, maneuvers, or flight segments not previously mentioned for which the present Light-Line concept could be utilized?

a. Can be used completely acceptable for:

b. Can be used partially for:

c. Cannot be used for:

16. What modification, in order of preference, would provide the most versatility for use of the Light-Line HUD?

	Modification/Addition	Maneuvers it would provide
#1		
#2		
#3		
#4		
etc.		

Please return to Major M. Tapia, IFC/RD, Ext 2785

Thank you for your time and cooperation